

## PREDICTIONS FOR THE DECAYS OF RADIALLY-EXCITED BARYONS

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We consider decays of the lowest-lying radially excited baryons. Assuming a single-quark decay approximation, and negligible configuration mixing, we make model-independent predictions for the partial decay widths to final states with a single meson. Masses of unobserved states are predicted using an old mass formula rederived using large- $N_c$  QCD. The momentum dependence of the one-body decay amplitude is determined phenomenologically by fitting to observed decays. Comparison of these predictions to experiment may shed light on whether the Roper resonance can be interpreted as a three-quark state.

**1 Introduction**

I will report results of some studies of excited baryon masses and decays<sup>1,2</sup>, concentrating mainly on the radially-excited baryon multiplet that includes the Roper resonance<sup>3</sup>.

Of course, the fundamental QCD degrees of freedom are quarks and gluons, but we must deal with observed states that are baryons and mesons. Our response is to use effective field theory. Here one first writes down all operators that are consistent with all known symmetries, and then use some method—in our case large  $N_C$ —to provide a size estimate for each operator. We discard small operators, keep as many of the large operators as possible and use them to calculate masses or decay amplitudes.

To illustrate how effective field theory and large  $N_C$  are used, the next section outlines a modern derivation of the Gürsey-Radicati<sup>4</sup> mass formula. The result is in itself useful for estimating masses of undiscovered radially excited baryons. After that, we show how we make predictions for decay widths of radially excited baryons, without assumptions about spatial wave functions.

**2 Mass formula**

We look at radially excited baryons where the spatial state, and so also the spin-flavor

state, is totally symmetric. There are 56 totally symmetric 3-quark states that one can make from  $u_\uparrow, u_\downarrow, d_\uparrow, d_\downarrow, s_\uparrow$ , and  $s_\downarrow$ , where the arrows indicate the spin projection. The ground states form the **56**, and the radially-excited states form the **56'**. The states are the  $N, \Lambda, \Sigma, \Xi, \Delta, \Sigma^*, \Xi^*$ , and  $\Omega$ .

The mass operators for these states are built from the spin  $S^i = \sum_\alpha \sigma_\alpha^i / 2$  (the sum is over the quarks  $\alpha$ ), the flavor operators  $T^a = \sum_\alpha \tau_\alpha^a / 2$  (where the  $\tau^a$  are a set of  $3 \times 3$  matrices), and the SU(6) operators

$$G^{ia} = \sum_\alpha \frac{1}{2} \sigma_\alpha^i \cdot \frac{1}{2} \tau_\alpha^a. \quad (1)$$

Terms in mass operators must be rotation symmetric, and flavor symmetric to leading order. Not all terms should be included. For example, in symmetric states matrix elements of  $T^2$  and  $G^2$  are linearly dependent on those of  $S^2$  and the unit operator<sup>5</sup>.

Flavor symmetry is not exact. The mass of the strange quark allows non-flavor symmetric terms in the effective mass operator, visible as unsummed flavor indices  $a = 8$  below. The effective mass operator is

$$\begin{aligned} H_{eff} = & a_1 1 + \frac{a_2}{N_C} S^2 + \epsilon a_3 T^8 + \frac{\epsilon}{N_C} a_4 S^i G^{i8} \\ & + \frac{\epsilon}{N_C^2} a_5 S^2 T^8 + \frac{\epsilon^2}{N_C} a_6 T^8 T^8 \\ & + \frac{\epsilon^2}{N_C^2} a_7 T^8 S^i G^{i8} + \frac{\epsilon^3}{N_C^2} T^8 T^8 T^8. \quad (2) \end{aligned}$$

There is an  $\epsilon$  for each violation of flavor symmetry, where  $\epsilon \approx 1/3$ . Also, a term that is a product of two or three operators comes from an interaction that has at least one or two gluon exchanges, and the strong coupling falls with number of colors as  $g^2 \sim 1/N_C$ . (A crucial theorem is that no perturbation theory diagrams fall slower in  $1/N_C$  than the lowest order ones<sup>5</sup>.)

Keeping the first four terms, taking the matrix elements, and reorganizing leads to

$$M = A + BN_s + C[I(I+1) - \frac{1}{4}N_s^2] + DS(S+1) \quad (3)$$

where  $N_s$  is the number of strange quarks. This is the Gürsey-Radicati<sup>4</sup> mass formula. We use it to predict masses of 4 undiscovered members of the **56'**, given that 4 are known.

### 3 The Decays **56'** $\rightarrow$ **56** + meson

Four of the 8 states in the **56'** are undiscovered or unconfirmed, and existing measurements have large uncertainty. However, we anticipate new results soon from the CLAS detector at CEBAF. One member of the **56'** is the Roper or N(1440), whose composition has been debated. Might it be a qqqG state<sup>6</sup>, a non-resonant cross section enhancement<sup>7</sup>, or just a 3-quark radial excitation<sup>8,9,10</sup>? Our predictions depend upon the last possibility.

We assume that only single quark operators are needed. Two quark operators were studied for decays of orbitally-excited states<sup>2</sup>, and found unnecessary. There is only one single quark operator here, so

$$H_{eff} \propto G^{ia} k^i \pi^a, \quad (4)$$

where  $k^i$  is the meson 3-momentum and  $\pi^a$  is a meson field operator.

One gets for the decay widths,

$$\Gamma = \frac{M_f}{6\pi M_i} k^3 f(k)^2 \sum |\langle B_f | G_{ja} | B_i \rangle|^2, \quad (5)$$

where  $f(k)$  parameterizes the momentum dependence of the amplitude. For the 7 measured decays it is well fit by  $f = (2.8 \pm 0.2)/k$ .

With this in hand, we can predict the widths for 22 decays. The detailed results are in<sup>3</sup>.

To summarize, we have shown how large  $N_C$  ideas provide a modern derivation of the old Gürsey-Radicati mass formula, and have predicted decay widths of the **56'**. The success of our predictions would bolster the view of the Roper as a 3-quark state.

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